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Time Division Multiple Access (TDMA)

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Time Division Multiple Access (TDMA)

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Abstract

In this communication, a concise overview of TDMA (time division multiple access) and its application to mobile communications shall be presented. It shall be motivated that TDMA, being a means of medium access control (MAC), facilitates both a high spectral capacity and a reasonably low implementation complexity. Finally, a further evolution of TDMA based systems toward the combination with CDMA (code division multiple access) will be illustrated. This combination became part of UMTS (universal mobile telecommunication system), known as UTRA TDD (UMTS terrestrial radio access time domain duplex) or TD/CDMA.

Keywords

CDMA, FDMA, GSM, multiple access, mobile communications, SDMA, TD/CDMA, TDMA, UMTS, UTRA TDD

1 Introduction

Communication, stemming from the Latin word for "common", is a most important desire of mankind. The combination of communication with mobility has accelerated the evolution of society world-wide, in particular during the past decade.

The history of mobile radio communication, however, is still young and dates back to the discovery of electromagnetic waves by the German physicist Heinrich Hertz in the nineteenth century. About hundred years ago, Gulielmo Marconi showed that long haul wireless communication was technically possible, using the radio principle based on Hertz's discovery and anticipating what we know as mobile radio, today [1].

With the invention of the cellular principle in the early seventies of the past century by engineers of AT&T Bell Labs, the basis for cellular mobile radio systems with high capacity was set [1]. In the early 1980s, the first commercial and civil mobile communication systems like the AMPS (American Mobile Phone Service), the NMT (Nordic Mobile Telecommunication), and the German C450 were introduced, allowing several hundreds of thousand subscribers [2].

However, technology could not provide digital signal processing at a reasonable degree. Hence, multiple access had to be FDMA (frequency division multiple access). Although FDMA is indispensable for the planning of mobile radio networks, it has some technological drawbacks which led to high priced base stations and cell phones [2].

However, during the past twenty years, the technological evolution provided us with unprecedented technological possibilities which help to overcome drawbacks of the early mobile radio systems:

- The development of digital signal processing became more and more mature.
- The integration density of microelectronic circuits increased beyond expected limits, providing increasing processing power in small ICs with low power consumtion.

In mobile radio, more freedom of choice of the multiple access scheme could be exploited to invent mobile radio systems with more flexibility, higher capacity and still lower price than the first generation which has relied on FDMA alone.

An increase in system capacity requires base stations which can handle an increased number of traffic channels. With respect to a reduced implementation complexity of the elaborate radio frequency design of base stations it is required to support several traffic channels per carrier. Furthermore, to realize radio frequency front ends with low complexity in cell phones, forward and reverse links should be separated in time. Therefore, TDMA (time division multiple access) provides these assets and hence became the choice for the second generation of mobile radio. Nonetheless, radio network planning remains an important requirement. Hence, TDMA had to be combined with the well established FDMA, resulting in a hybrid multiple access scheme which is often termed F/TDMA (frequency divided time division multiple access) [3]. These ideas and their further evolutions shall be considered in what follows.

This communication is structured as follows: In Sect. 2, multiple access principles and hybrid multiple access schemes, which are feasible in mobile radio, shall be discussed. Sect. 3 presents signal and system structures used in TDMA systems. The author shall give a brief discussion of important TDMA systems for mobile communication, in Sect. 4. An evolution of TDMA toward the third generation of mobile communications, termed UMTS (universal mobile telecommunication system), will be presented in Sect. 5. Sect. 6 presents concluding remarks.

2 Multiple access principles and hybrid multiple access schemes

In Tab. 1 [3], an overview of the four classical multiple access principles FDMA, TDMA, CDMA (code division multiple access) and SDMA (space division multiple access) is presented. Besides the basic concepts of these multiple access principles, the cellular aspect and an overall evaluation are offered in Tab. 1.

TDMA, CDMA, and SDMA have become feasible with the introduction of digital technology. However, CDMA was not well understood in civil communications engineering in the 1980s. Only after considerable research effort undertaken in the past two decades, CDMA has been identified as a superb means for mobile multimedia and is therefore deployed in UMTS [4],[5]. With the exception of the well-known ANSI/TIA-95, second generation mobile radio systems did not use CDMA.

In the context of multiple access, SDMA, which needs still expensive smart antennas, has not yet been deployed. However, it is anticipated that SDMA type technologies will be introduced in upcoming releases of UMTS. SDMA can be regarded as a natural extension of the other three multiple access principles and will thus not be considered separately in this communication.

According to Tab. 1, all multiple access principles have their specific advantages and drawbacks. To benefit from their advantages and to alleviate the effect of the drawbacks, a combination of multiple access principles, resulting in hybrid multiple access schemes, is recommendable.

Considering FDMA, TDMA and CDMA, four hybrid multiple access schemes are conceivable [3], [4], namely the aforementioned F/TDMA, and, furthermore, F/CDMA (frequency divided code division multiple access), T/CDMA (time divided code division

multiple access) and F/T/CDMA (frequency and time divided code division multiple access), cf. Fig. 1.

As already discussed, F/TDMA has been chosen for most second generation mobile radio systems except for ANSI/TIA-95 which deploys F/CDMA. Since T/CDMA does not support radio network planning it has not yet been taken into account for communication systems. F/T/CDMA has been identified as a viable multiple access scheme for the UTRA TDD (UMTS terrestrial radio access time domain duplex) mode. This mode is known as TD/CDMA, as well, and presents an extension of F/TDMA, cf. Sect. 5.

In what follows, we assume that TDMA is always combined with FDMA resulting in F/TDMA for the reasons presented in this section. Since TDMA is the most significant part of this hybrid multiple access scheme, the expression TDMA refers to F/TDMA in the sequel.

3 Signal and system structures for TDMA

3.1 Physical layer subscriber signal structures

The physical layer subscriber signals carry the data sequences, which shall be transmitted to the receiver. These data sequences consist of encoded subscriber data, which can be any type of information stemming from higher layers, i.e. layers above the physical layer. These subscriber data could e.g. be digitally encoded speech. The physical layer subscriber signals have to contain signaling information which are required to set up, maintain and release the connection between transmitter and receiver [3].

Since mobile communication is considered, a time-varying multipath channel with an unknown impulse response must be taken into account. To support coherent data detection, channel estimation must be carried out at least once per subscriber time slot. This channel estimation is based on training sequences, which are part of the aforementioned signaling information and which must therefore be embedded in the physical layer subscriber signals. Furthermore, the physical layer subscriber signals are concluded by guard periods of duration T_g in order to guarantee a reasonable separation between consecutive physical layer subscriber signals [3].

As illustrated in Sect. 2 and Tab. 1, TDMA allows a subscriber to be active only for a short time before the next period of activity occurs in the next TDMA frame. A typical duration of a subscriber time slot, T_u, is about 0.5 ms whereas a TDMA frame comprises of several subscriber time slots and has a typical duration, T_{fr}, in the order of 5 ms. Hence, the physical layer subscriber signals have a finite duration of T_u. Such signals are usually termed bursts.

Fig. 2 shows two commonly used burst types [3]. The first burst type, cf. Fig. 2a, uses a preamble, which contains the signaling information including the aforementioned training sequence. When a preamble is used, the aforementioned channel estimation can take place at the beginning of the signal reception. The channel estimate, which is based on noisy samples, is effected by estimation errors due to noise in the received signal. Owing to these estimation errors, the data detection can only be quasi-coherent. The noisy channel estimates are fed into the quasi-coherent data detector, which carries out the data detection based on the sample values obtained after the reception of the preamble. Ideally, this quasi-coherent data detection can be carried out without having to store any sample values.

However, in the case of a low correlation time of the mobile radio channel, i.e. at high mobile velocities, the true channel impulse response varies over the duration T_u of the subscriber

increases nonlinearly with increasing distance from the preamble. In the case of long bursts this effect leads to considerable systematic errors resulting in dramatic degradations of the quasi-coherent data detection, i.e. of the bit error ratio at a given E_b/N_0.

In order to alleviate this effect, midambles are used instead of preambles, cf. Fig. 2b. In this case, the data are divided in two parts, usually of equal size and half as long as the data carrying part shown in Fig. 2a. The signaling information is located between these two parts. Then, the effect of the above-mentioned systematic errors on the bit error ratio is considerably smaller. However, in order to carry out a quasi-coherent data detection, at least those samples associated with the first part of encoded subscriber data has to be stored before the channel estimation can be carried out. Nevertheless, thanks to high integration densities in CMOS technology, memory ICs or embedded on-chip memories are available at a reasonably low price alleviating this drawback.

A third possibility, using a postamble, suffers from all drawbacks of the aforementioned two burst types without having further advantages. To the knowledge of the author, this third possibility has not yet been implemented and will not be further considered in this communication

3.2 System structure

Fig. 3 shows the corresponding system structure for the physical layer data path between the signal source and the signal sink, cf. e.g. [3]. The system structure consists of a transmitter, a receiver and the transmission channel.

The transmitter contains source and channel encoders, an interleaver, a burst builder, a modulator, digital and analog filters, the analog RF/IF transmit front end and at least one transmit antenna. The receiver, in particular the base station receiver, consists of up to K_a receive antennas, K_a RF/IF receive front ends, K_a ADCs (analog-to-digital converters), an adaptive (quasi-) coherent data detector, a de-interleaver and channel and source decoders.

Usually, hard decided, decoded information combined with the corresponding soft/reliability information are exchanged between the different receiver stages. In this way, a desirably good system performance can be guaranteed.

The system structure shown in Fig. 3 is the basis for the extension to TD/CDMA used in UMTS, see Sect. 5. There, the corresponding system structure shall be discussed.

4 Two important TDMA systems for mobile communication

4.1 Overview

In Fig. 4 the vision generated by the Wireless Strategic Initiative (www.ist-wsi.org) on the further evolution of mobile radio is summarized. The two most important and most successful TDMA systems are the European GSM (global system for mobile communication) [2] and the American UWC-136 (universal wireless communications) [5].

Both TDMA systems started with circuit switched data transmission. In its second phase, GSM was extended to high speed circuit switched data (HSCSD) with minimal data rates of about 14.4 kbit/s and typical data rates between about 50 to 60 kbit/s. The corresponding first version of UWC 136 was termed D-AMPS (digital advanced mobile phone service) or IS-54. Both systems were further developed to incorporate packet switching based on GPRS (general

evolution). Typically, the different EDGE variants provide data rates of about 144 kbit/s with a maximum around 400 kbit/s. GPRS and EDGE evolutions will be part of the family of third generation mobile communication systems, briefly termed 3G mobile radio systems, with data rates above 400 kbit/s [5],[6],[7],[8],[9].

4.2 Global System for Mobile Communication (GSM)

Doubtlessly, the most successful mobile communication system is GSM. Today, GSM provides a multitude of both circuit and packet switched services and applications including internet access by e.g. using WAP (wireless application protocol) or i-mode. Maximal data rates are currently around 50 kbit/s. However, an increase up to around 400 kbit/s has already been introduced into the GSM standard.

Tab. 2 presents important system parameters of GSM, and Fig. 5 gives a comparison between the energy density spectra of well-known digital modulation schemes with those of GMSK (Gaussian minimum shift keying) and the GMSK main impulse [2],[3],[5],[6].

5 TD/CDMA

As mentioned before, F/TDMA lends itself for further extensions to 3G mobile radio systems. In the early 1990s, the combination of F/TDMA with CDMA was presented, resulting in the hybrid multiple access scheme F/T/CDMA already considered in Sect. 2 and Fig. 1. Now, up to K subscribers could operate simultaneously within a TDMA time slot [3],[5].

A major problem to be solved in a CDMA based system is the near-far problem. In order to alleviate the necessity of fast power control, which cannot be provided at high velocities when a TDMA component is used, multi-user detection is a must in F/T/CDMA. It has been shown that suboptimal joint detection (JD) techniques based on block linear equalization and block decision feedback equalization lend themselves as viable means for such F/T/CDMA based systems.

The channel estimation to be used must be capable of estimating a multitude of simultaneous transmission channels in the uplink. Steiner proposed a means of generating good training sequences for this purpose and proposed a novel channel estimator [10], sometimes termed the Steiner estimator. These milestone developments, the JD techniques and the Steiner estimator, paved the way toward what is known as TD/CDMA or UTRA TDD, today [3],[5].

By moderately modifying the system structure shown in Fig. 3 the corresponding system structure for TD/CDMA can be found, cf. Fig. 6. In Fig. 7, the physical layer subscriber signal is shown schematically. Both system and signal structures are consequent evolutions toward more multimedia in mobile communications, and it can be anticipated that TDMA components will remain important in the future.

6 Conclusions

In this communication, TDMA as a viable means to solve the multiple access problem in mobile communication was discussed. Besides giving an overview of the four classical multiple access principles, hybrid multiple access schemes were illustrated. Furthermore, we discussed both physical layer signal structures and the corresponding system structures for TDMA systems deployed in mobile communications. Finally, important TDMA systems and the evolution toward 3G mobile radio systems were briefly sketched.

To conclude, it shall be mentioned that TDMA provides excellent features also in short range communication systems. Therefore, also wireless local area networks as well as some future wireless communication system concepts "beyond 3G" rely on TDMA components.

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	Multiple access principle		
	FDMA	TDMA	CDMA
General features			
Basis	Division of system bandwidth B into N_F directly adjacent, disjoint subscriber frequency bands of width B_u ($B_u \ll B$)	Division of the transmission period into directly adjacent, disjoint TDMA frames of duration T_{fr} comprising of N_Z subscriber time slots of duration T_u ($T_u \ll T_{fr}$)	Spectrum spreading by using K_g subscriber specific CDMA code
Subscriber activity	N_F subscribers are simultaneously and continuously active; each subscriber uses a single subscriber frequency band	N_Z subscribers are consecutively active for a short period; each subscriber uses a single subscriber time slot per TDMA frame	K_g subscribers are simultaneous continuously active; each subsc single subscriber specific CDM
Differentiation between subscriber signals	In the frequency domain	In the time domain	Based on CDMA codes
Separating the subscriber signals …	… by filtering	... by deploying synchronization; guard periods between consecutively transmitted subscriber signals are required	... by deploying synchronization user detection (SUD) or multi-u detection (MUD)
Area of deployment	Analog and digital	Digital	Digital
Advantages	Simple; robust; supports network planning; simple equalization	Frequency diversity; receiver is insensitive to time variation of the mobile radio channel; time diversity; high spectral capacity owing to missing intra cell interference; reduced complexity in radio frequency design for cell phones and base stations possible; allows time domain duplexing (TDD)	Frequency diversity; receiver is to time variation of the mobile r channel; simple equalizers; inte diversity; soft degradation; no n planning required; flexibility; re complexity in radio frequency d base stations possible
Disadvantages	Low flexibility; little frequency diversity; receiver sensitive to time variation of the mobile radio channel; little interference diversity; space diversity is necessary; considerable complexity in radio frequency design for cell phones and base stations	Low flexibility; latencies; equalizer is required due to intersymbol interference; little interference diversity; global synchronization of all subscribers, at least in a cell	Low spectral capacity without n detection
Cellular aspects			
Typical frequency re-use factor	$r > 1$ due to intercell interference	$r > 1$ due to intercell interference	$r \approx 1$
Evaluation			
	Required for mobile radio; combination with TDMA and/or CDMA is favorable	Applicable in mobile radio; combination with FDMA is strongly suggested and with CDMA is favorable	Applicable in mobile radio; ; co with FDMA is strongly suggest with TDMA is favorable

Tab. 1. Comparison of multiple access principles [3].

Multiple access scheme	F/TDMA
Modulation scheme	Phases 1,2,2+: GMSK (Gaussian minimum shift keying) EDGE: GMSK, (3/8)π-Offset-8-PSK (8-ary Phase Shift Keying) with spectral forming by GMSK main impulse
Subscriber bandwidth	200 kHz
Symbol rate	270.833 ksymbols/s
Duration of a TDMA frame, T_{fr}	4.615 ms
Number of subscriber time slots per TDMA frame	8
Uplink (reverse link) frequency bands	880 ... 915 (GSM 900, e.g. German D networks) 1720...1785 (DCS 1800, e.g. German E networks) 1930...1990 (American GSM 1900)
Downlink (forward link) frequency bands	935... 960 (GSM 900, e.g. German D networks) 1805...1880 (DCS 1800, e.g. German E networks) 1850...1910 (American GSM 1900)
Maximal information rate per subscriber	Speech full rate: 13 kbit/s half rate: 6.5 kbit/s enhanced full rate: 12.2 kbit/s Data TCH/9.6 (phase 1): 9.6 kbit/s phase 2+ HSCSD: 115.2 kbit/s phase 2+ GPRS: 171.2 kbit/s (four coding schemes, today, only coding scheme CS-2 is used; three classes of mobile equipment; 18 multi-slot classes, today, classes 4 and 8 are usually implemented, cf. www.csdmag.com) EDGE: packet switching with data rates of minimally 384 kbit/s for velocities below 100 km/h; packet switching with data rates of minimally 144.4 kbit/s for velocities between 100 km/h and 250 km/h
Frequency hopping (optional)	1 hop per TDMA frame, i.e. 217 hops/s

Tab. 2. Important system parameters of GSM, cf. e.g. [5],[6].

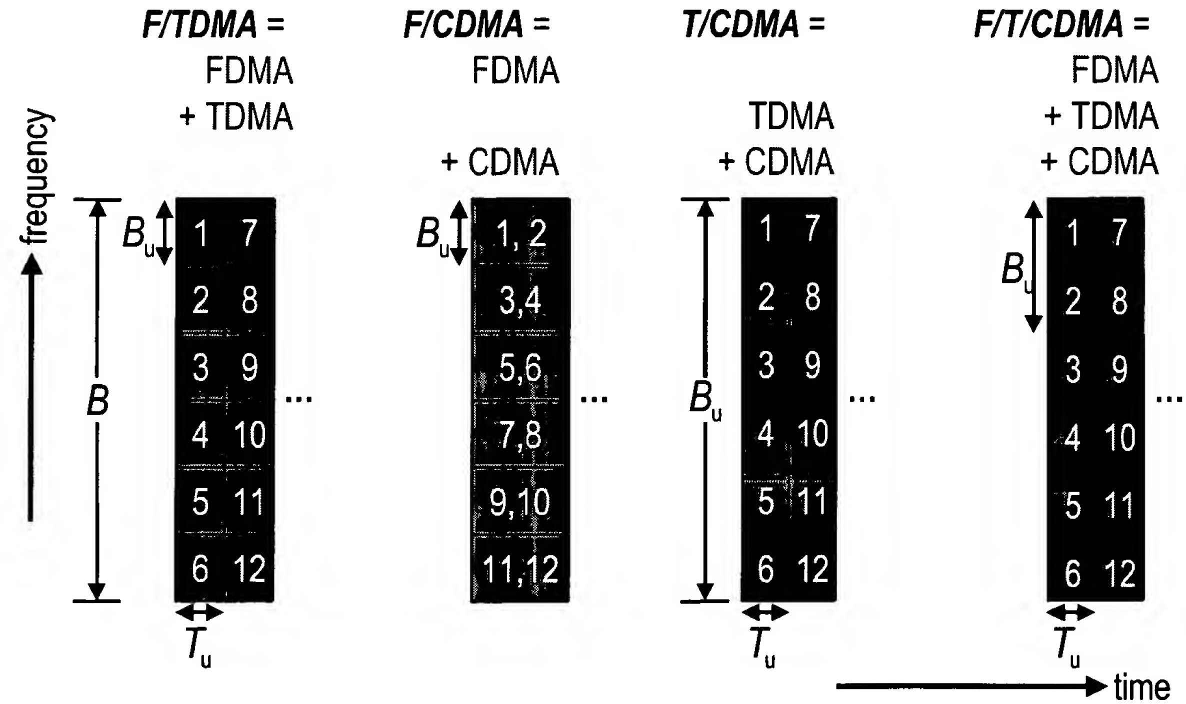

Fig. 1. Hybrid multiple access schemes, cf. e.g. [3],[4].

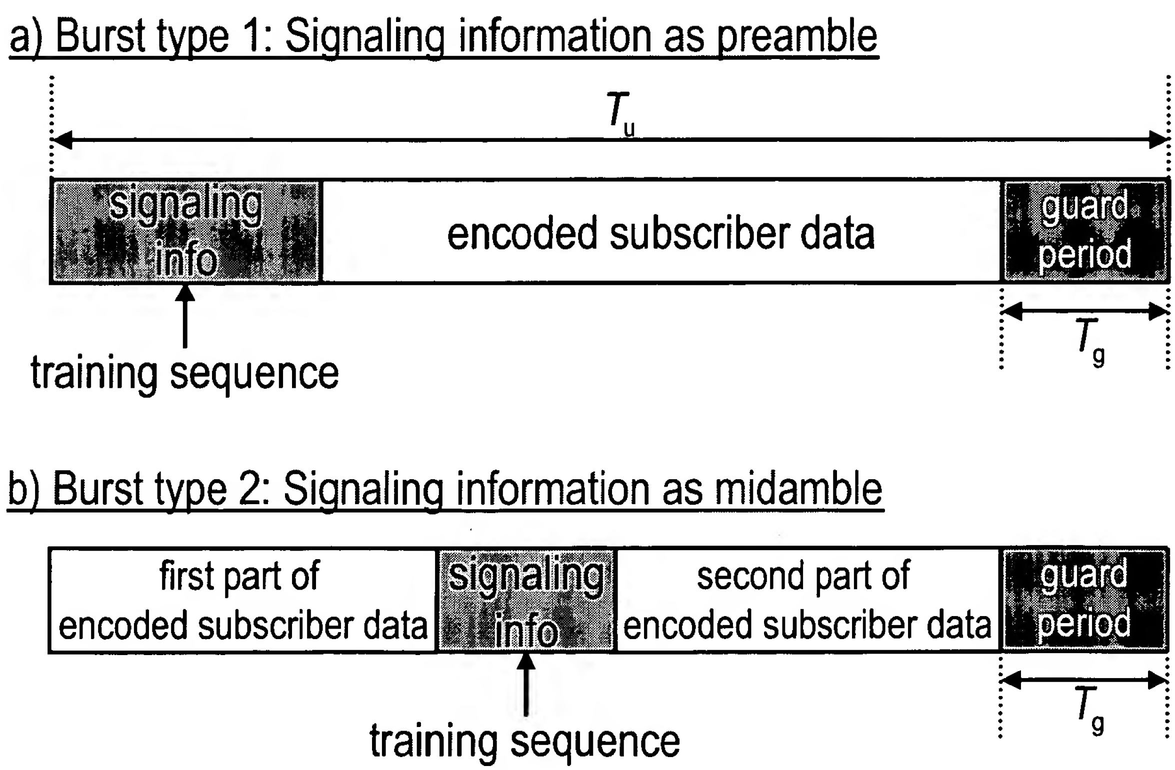

Fig. 2. Burst types for TDMA [3].

a) Burst type 1: Signaling information as preamble
b) Burst type 2: Signaling information as midamble

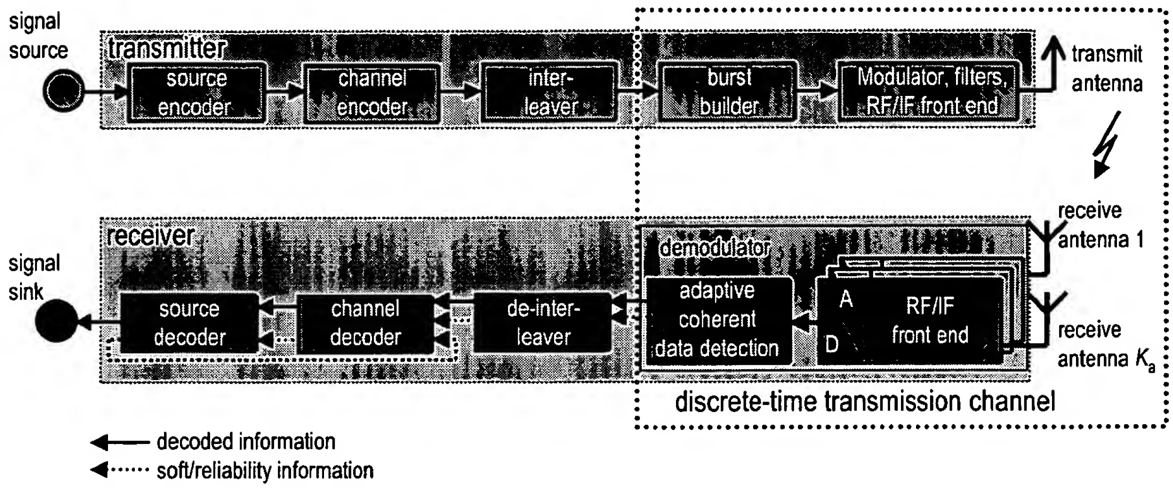

Fig. 3. System structure for TDMA, cf. e.g. [3].

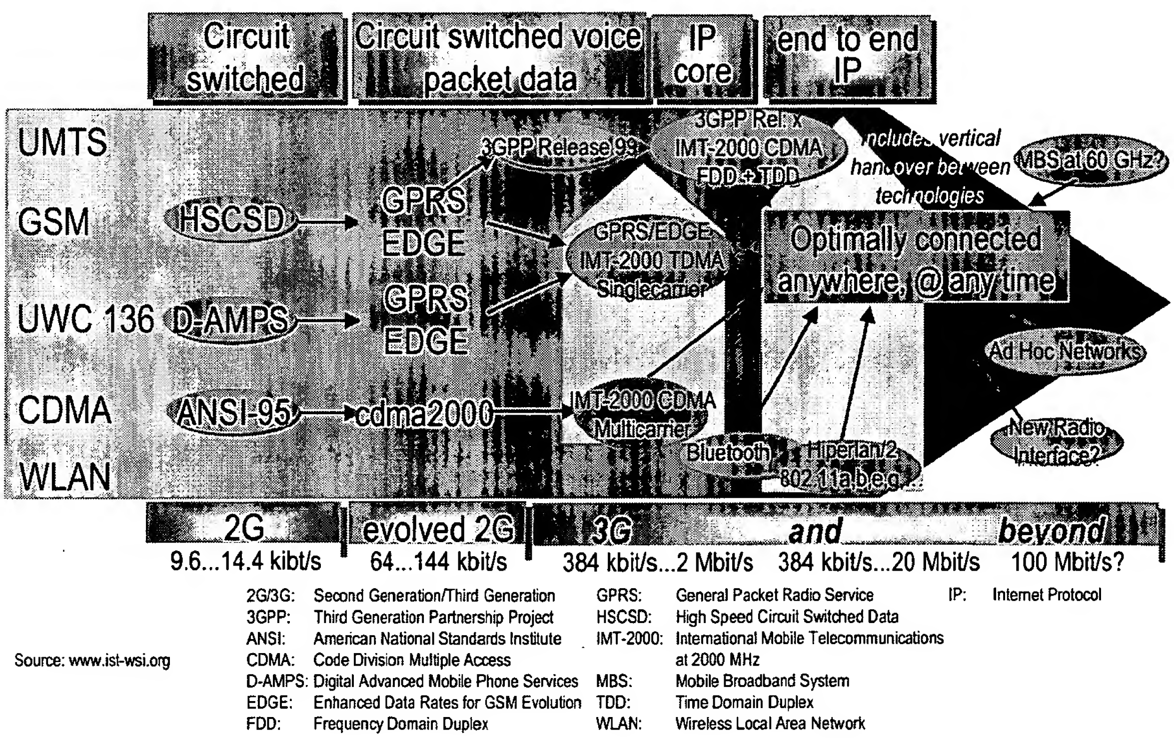

Fig. 4. Evolution of wireless communications (source: www.ist-wsi.org).

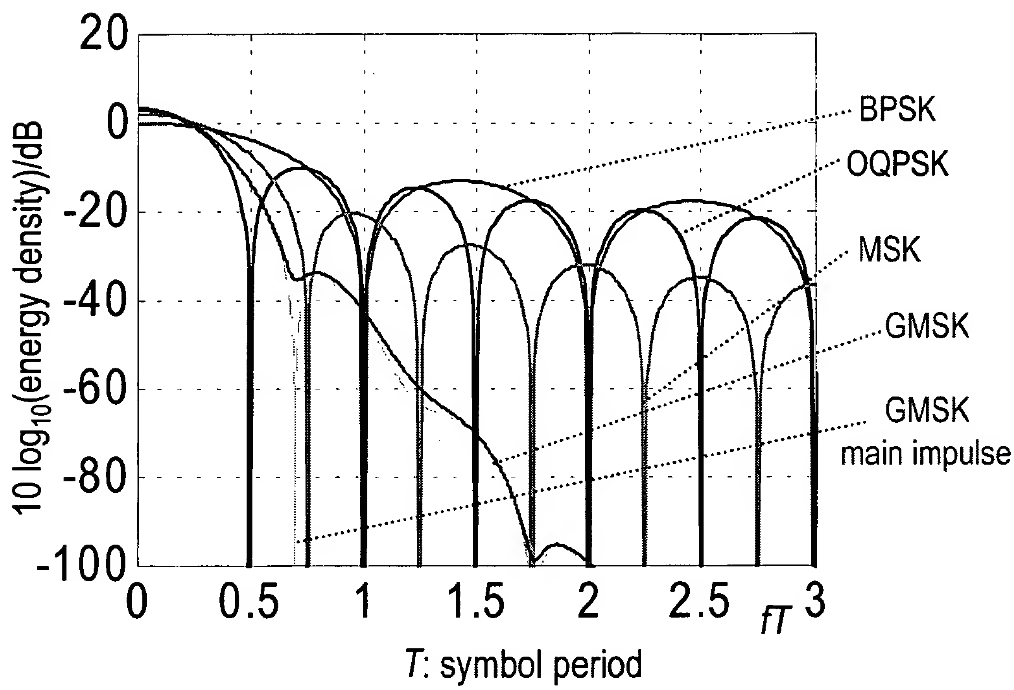

Fig. 5. Energy density spectra.

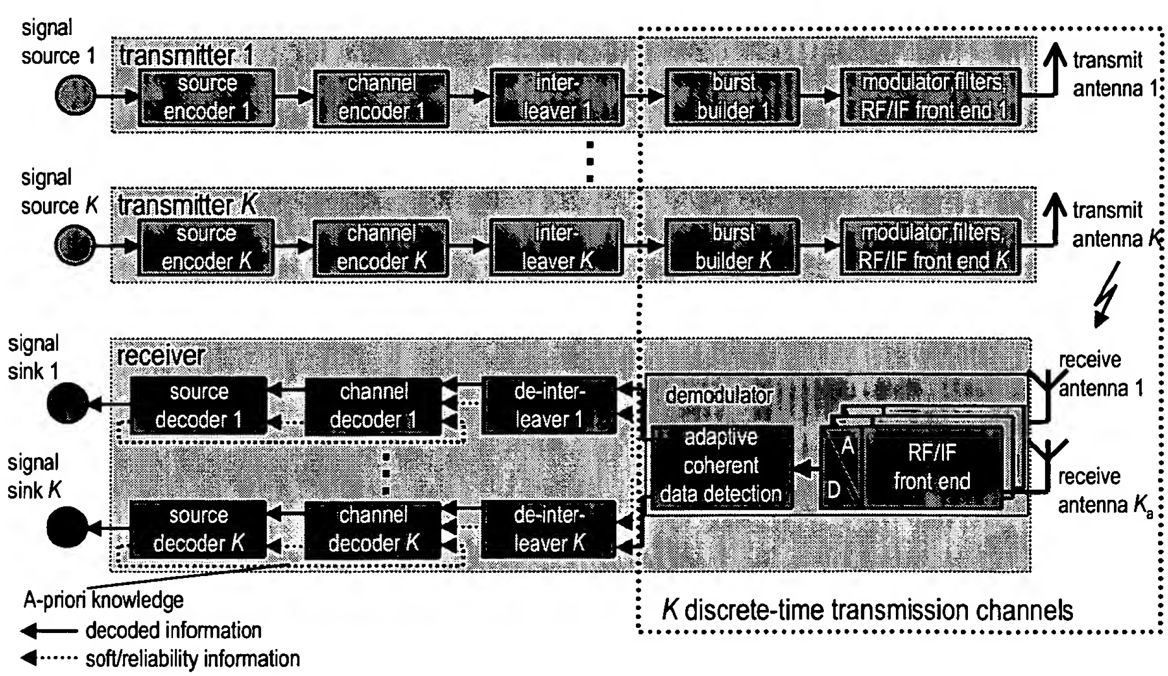

Fig. 6. System structure for TD/CDMA, cf. e.g. [3].

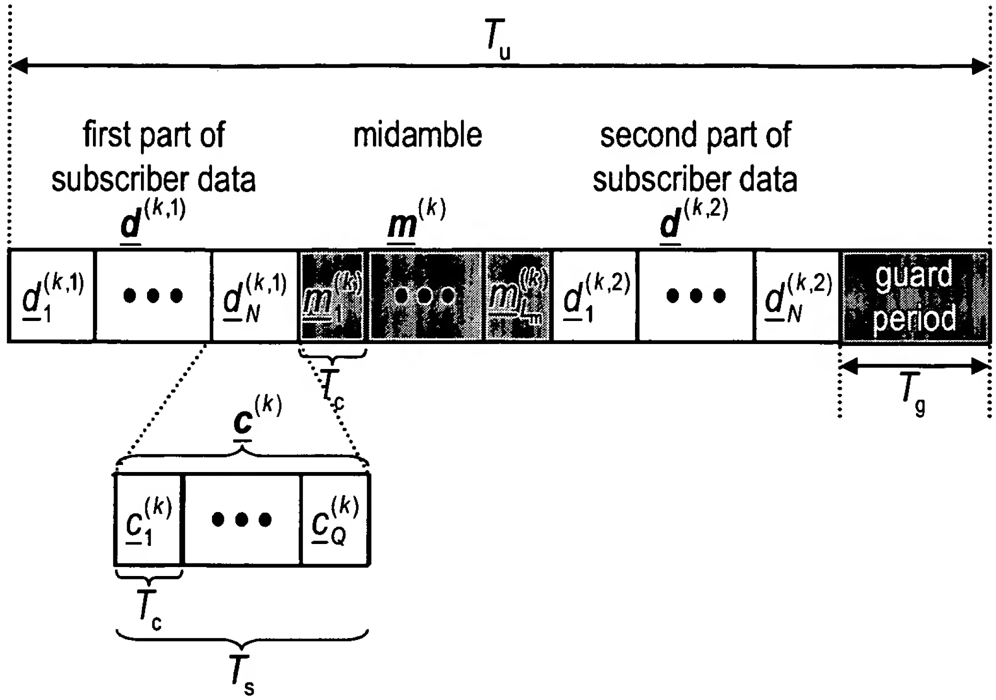

Fig. 7. Data structure in a TD/CDMA burst [3].